

# Testing CP Conservation at KLOE

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## Abstract

A proposal for maintaining CP conservation in  $K_L^0$  decays is resumed, by adding a heterodox hypothesis. One recovers a consistent picture with a  $2\pi$   $K_L^0$  decay branching ratio proportional to the vertical  $K_L^0$  displacement. This can be clearly tested at the KLOE experiment, where important vertical  $K_L^0$  displacements occur.

## 1 Introduction

Bernstein, Cabibbo, and Lee [1], after the discovery [2] of  $2\pi$  decay of  $K_L^0$  and the explanatory hypothesis of CP violation, considered the possibility that  $2\pi$  decay of  $K_L^0$  could be due to the effect of an external field, thus saving CP symmetry [3]. In this paper we try to resume the external-field hypothesis and the related CP conservation, by introducing the heterodox assumption that the gravitational field has a scalar component acting in opposite ways on the  $K^0$  and the  $\bar{K}^0$  mixed in the  $|K_L^0\rangle$  state. When suitably developed, this assumption gives a picture which allows some simple predictions for the KLOE experiment at the DAΦNE collider in Frascati. For the first time, KLOE allows great vertical  $K_L^0$  displacements, thus permitting the Earth's gravitational field to manifest its possible effects clearly. The chief attraction of the present approach is on one hand the easiness of testing it at KLOE,

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and on the other hand the simplicity introduced by CP conservation. Some of the challenging questions opened by the repulsive gravitational coupling are briefly considered.

## 2 $K_L^0$ decays and a scalar component of the gravitational field

As is well known, the  $K^0 - \overline{K}^0$  system has two *eigenstates* of the CP operator. If one assumes that CP is conserved in all decays, the physical  $K_S^0$  coincides with the state  $|K_S^0\rangle = (|K^0\rangle + |\overline{K}^0\rangle)/\sqrt{2}$  having CP *eigenvalue* +1. It quickly decays with mean life  $\tau_S$ , practically always into two pions (CP *eigenvalue* +1). The other state  $|K_L^0\rangle = (|K^0\rangle - |\overline{K}^0\rangle)/\sqrt{2}$  with CP *eigenvalue* -1, coincides with the physical  $K_L^0$ , which decays slowly (mean life  $\tau_L \approx 600 \tau_S$ ) along a lot of channels. Some of these channels have final states with CP eigenvalue +1. This long-lived state can be thought of as a fast mixing of  $|K^0\rangle$  and  $|\overline{K}^0\rangle$  performing the virtual oscillation:  $K^0 \rightarrow 2\pi \rightarrow \overline{K}^0 \rightarrow 2\pi \rightarrow K^0$ , with a frequency of the order of  $1/\tau_S$ , and a mixing energy  $\hbar/\tau_S \approx 7 \times 10^{-6}$  eV.

Although it's been almost forty years since the experimental discovery of  $2\pi$  decay of  $K_L^0$  [2], the origin of the CP violation, usually assumed to be at the root of  $2\pi$   $K_L^0$  decay, is still judged as not fully understood. Indeed as is well known, within the Standard Model, one can accommodate CP violation through a parametrization of Cabibbo-Kobayashi-Maskawa's matrix (see, for instance, [4] [5] [6]).

Bernstein, Cabibbo, and Lee [1] a year after the discovery of  $2\pi$   $K_L^0$  decay, attempted to reconcile CP conservation with it. They analyzed the possibility that  $2\pi$  decay could be explained in terms of the effect of an external field (they considered the three values of the intermediate-boson spin  $J$ : 0, 1, or 2), producing a potential-energy difference  $+V/2$  for  $K^0$  but  $-V/2$  for  $\overline{K}^0$ . By means of a relativistic time evolution equation, they found for the complex  $2\pi$   $K_L^0$  branching ratio  $\epsilon$ , when  $V \ll \hbar/\tau_S$ :

$$\epsilon \approx \frac{\gamma V(\gamma)}{2} \left[ (m_L - m_S) c^2 - \frac{i\hbar}{2} \left( \frac{1}{\tau_S} - \frac{1}{\tau_L} \right) \right]^{-1/2}, \quad (1)$$

where  $\gamma$  is the kaon Lorentz factor in the laboratory frame, and  $m_L$  and  $m_S$  are the masses of  $K_L^0$  and  $K_S^0$ , respectively. Starting from general assumptions for the classical Lagrangian, the intrinsic  $V$  dependence on  $\gamma$  must be

expected to be:  $V(\gamma) = V_0 \gamma^{J-1}$  [7], where  $V_0$  is the potential energy seen by the particle when at rest, relative to the field source. In Ref.[1], the assumption that  $V_0$  is the fourth component of an unknown vector field ( $J = 1$ ), has been made, then, from (1), it follows that  $|\epsilon|$  must be proportional to  $\gamma$ . After a few years, the experiments [8][9][10] showed that  $|\epsilon|$  was independent of  $\gamma$ . Therefore the external-field CP-conserving interpretation of  $2\pi K_L^0$  decay was dismissed.

Actually, if in (1) one considers a scalar field ( $J = 0$ ), one has  $|\epsilon|$  independent of  $\gamma$ , as the experiments require. The questions arise whether this field can be identified with a scalar component of the Earth's gravitational field, as well as through this scalar component, the Earth can exert an anti-gravitational force on  $\overline{K^0}$ . These questions raise a web of problems, which will be only briefly considered below.

By assuming that the Earth's gravitational field has a scalar component, and by identifying  $V_0/2$  with  $m_K g_E \Delta\zeta$  [11], with  $m_K$  the kaon mass,  $g_E$  the Earth fall acceleration, and  $\Delta\zeta$  the vertical  $K_L^0$  displacement, one finds:

$$|\epsilon| \approx m_K g_E \Delta\zeta \left[ (m_L - m_S)^2 c^4 + \frac{\hbar^2}{4} \left( \frac{1}{\tau_S} - \frac{1}{\tau_L} \right)^2 \right]^{-1/2} = m_K g_E \Delta\zeta \Lambda, \quad (2)$$

where  $\Lambda = (1.231 \pm 0.002) \times 10^{24} \text{ J}^{-1}$ , as follows from using standard values [12] for kaon properties.

For KLOE,  $\Delta\zeta$  is the vertical displacement between the small intersection region of DA  $\Phi$ NE  $e^-$  and  $e^+$  beams (within which  $\Phi$  decays into kaons) and the  $K_L^0$  decay vertex. The maximum effective  $\Delta\zeta$  is roughly 1.5 m, for which (2) gives  $|\epsilon| = |\eta_{+-}| \approx 15 \times 10^{-3}$ , that is, roughly seven times the standard value ( $|\eta_{+-}| = (2.27 \pm 0.02) \times 10^{-3}$  [12]). According to this approach, the first effect that KLOE should have to observe, is an average  $|\eta_{+-}|$  value three to four times greater than the standard one. This large average  $|\eta_{+-}|$  could be observed with a number of  $K_L^0$  much smaller than the number forecast for KLOE design targets.

For instance, when collecting a sample of  $10^4 K_L^0$  with a  $\Delta\zeta$  within 0.95 m and 1.05 m (inside the horizontal slabs below and above the production point), one finds one hundred of  $K_L^0$  decaying into two charged pions, that is, a branching ratio  $|\eta_{+-}| = (10 \pm 1) \times 10^{-3}$ . Such a value would practically exclude the standard picture. Better information can of course be obtained by collecting *e.g.*  $10^6 K_L^0$  inside the whole KLOE volume. By subdividing them,

for instance, in six bins of  $\Delta\zeta$  between 0.3 m and 1.5 m, one may look for the possible proportionality relationship between  $|\eta_{+-}|$  and  $\Delta\zeta$ , and should it be found, by comparing the experimental slope with  $\Lambda m_K g_E = (1070 \pm 2) \times 10^{-5} \text{ m}^{-1}$ , where  $m_K = 497.672 \pm 0.031 \text{ MeV}$  [12] and  $g_E = 9.8 \text{ ms}^{-2}$ .

Moreover, one must find small values of  $|\eta_{+-}|$  at low  $\Delta\zeta$ . For instance, once  $10^6 K_L^0$  are collected, roughly  $7.5 \times 10^4 K_L^0$  decays along all channels, will be observed inside a horizontal slab 20 cm thick placed from 10 cm below to 10 cm above the production point. With the standard  $|\eta_{+-}|$  value one must expect  $170 \pm 13$  decays into two charged pions, while following the present approach one must detect only  $40 \pm 7$  decays, with a difference of nearly 9 standard deviations.

Most information on the  $K^0 - \overline{K}^0$  system, has been obtained from horizontal-beam experiments, to which of course the present gravitational interpretation must apply as well. When considering a nearly horizontal  $K_L^0$  beam,  $V_0$  can be due to the gravitational fields of the Earth and of the Sun. At the Earth's surface, the latter is much smaller than the former. For the Earth's field the vertical effective displacements are rather small since they are mainly linked to the  $K_L^0$  beam divergency. For the Sun's field the displacements projected along the field direction, can also be a few thousand times greater when considering long  $K_L^0$  beams.

The papers reporting experimental  $|\epsilon|$  values, give in general little information, if any, concerning beam geometry. However, the first relevant information on decay amplitudes, comes from the experiments [2][8][9][10][13], where the  $K_L^0$  beam length was markedly shorter than 100 m. Thus, the unique possibility of having  $V_0$  different from zero, is linked to a possible effect of the Earth's field, when a vertical displacement due to a small vertical component of  $K_L^0$  velocity, occurs. A first set of experiments up to 1972 [2][8][9][10], reported  $|\epsilon|$  values grouped around  $1.95 \times 10^{-3}$ , and all have roughly  $\Delta\zeta \approx 0.2 \text{ m}$ , as far as is possible to judge from the beam size in the decay region. By taking  $\Delta\zeta = (0.20 \pm 0.04) \text{ m}$  (a somewhat arbitrary 20% error has been assumed), and  $|\epsilon| = (1.95 \pm 0.2) \times 10^{-3}$  as correlated values, eq.(2) gives:

$$g_E = |\epsilon| / (\Lambda m_K \Delta\zeta) = 8.9 \pm 2.7 \text{ m s}^{-2},$$

which is consistent with the standard  $g_E$  value. Since 1973 higher values of  $|\epsilon|$  have been reported [13] grouped finally around  $2.27 \times 10^{-3}$  (the presently accepted value), perhaps with slightly larger  $\Delta\zeta$  values.

If the present gravitational interpretation applies, the effect of the Earth's

field can introduce important biases in an experiment such as CPLEAR at CERN, where the effective maximum vertical displacement is roughly 0.4 m. This would make it necessary to reanalyze all CPLEAR results, such as those concerning CP violation parameters and the so-called direct T-reversal violation.

The four experiments NA31 and NA48 at CERN, and E731 and KTeV at Fermilab, have utilized and utilize long  $K_L^0$  horizontal beams. Thus, their results could be biased by the effects of both the Earth's and the Sun's field. The latter effect depends on the beam length projected along the direction of the solar field, and this projected length continuously varies owing to Earth rotation and revolution. Thus, these long-beam experiments could be affected by non-trivial systematic errors, and their results, such as those concerning  $Re(\epsilon'/\epsilon)$  and time reversal  $T$  violation, would all have to be reanalyzed.

Among the various topics concerning the  $K^0$ - $\overline{K}^0$  system, let us consider an argument due to Sakurai and Wattemberg [14]. They elegantly argued that CP violation in  $2\pi$   $K_L^0$  decay is conclusively demonstrated by so-called soft regeneration, first observed by Fitch *et al.* [9]. This argument does not apply if one assumes that  $K^0$  and  $\overline{K}^0$  have opposite gravitational behavior, with the possibility that CP is an exact symmetry [15].

Coherently with the starting hypothesis of antigravity, one must expect that, for instance, antiprotons, antineutrons, and antiatoms are gravitationally repelled from the Earth, thus *antifalling* with the acceleration modulus  $g_E$ . One must take into account that antigravity, besides introducing a lot of problems in the standard physical picture, cannot coexist with the equivalence principle [16]. Actually, it seems possible to maintain the agreement with a very large part of the known phenomena, by embedding the antigravity assumption in a set of suitable hypotheses [17]. In this way, it seems possible to avoid all paradoxes and difficulties (such as violation of energy conservation, causality violation, possible CPT violations, etc.), which antigravity implies when directly inserted into the standard physical picture. It also seems possible to circumvent any conflict with the so-well tested proportionality between the inertial and the gravitational mass [18].

### 3 Concluding remarks

For the first time the KLOE experiment at DAΦNE offers the possibility of having important vertical  $K_L^0$  displacements, thus allowing the Earth's gravitational field to manifest its possible effects clearly. The proposal advanced in 1964 by Bernstein, Cabibbo, and Lee has been resumed, by adding to it the heterodox hypothesis that the gravitational field has a scalar component acting in opposite ways on the  $K^0$  and  $\overline{K}^0$  mixed in  $|K_L^0\rangle$ . We have shown that the CP-conserving mechanism seems to fit the known  $K_L^0$  properties well. The main new consequence is the proportionality between the modulus of  $2\pi K_L^0$  decay branching ratio and the vertical  $K_L^0$  displacement. At KLOE, this proportionality should be observed with a relatively small number of  $2\pi K_L^0$  decays. If KLOE data should validate this proportionality, it would become necessary to consider the above sketched questions, and many other related topics and problems as well.

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- [15] In the so-called soft regeneration experiments [9], low-density regenerators are used, so that the modulus of the complex regeneration parameter  $\rho$  is roughly equal to  $|\epsilon|$ . The experiments show that there is interference between  $\rho$  and  $\epsilon$  and that, therefore, the final two-pion states of  $K_S^0$  and  $K_L^0$  decays, are identical. This identity provides an absolute criterion for distinguishing matter from antimatter, because in an experiment performed on an Antiearth the relative  $\rho$  and  $\epsilon$  sign would change, thus exhibiting a matter-antimatter asymmetry, that is, a clear signature of CP violation. The Sakurai-Wattemberg argument does not apply if one assumes that  $K^0$  and  $\overline{K}^0$  have opposite gravitational behavior. In fact,

when observing  $2\pi K_L^0$  decay on an Antiearth, not only  $\rho$  would reverse its sign as in the standard physical picture, but also  $\epsilon$  would do the same, owing to the reversed gravitational interactions of both  $K^0$  and  $\overline{K}^0$ . Then, the relative sign of  $\rho$  and  $\epsilon$  would not change, showing complete symmetry between matter and antimatter, thus reopening the possibility that CP is an exact symmetry.

- [16] In fact, it would be easy in principle for an experimenter to distinguish whether he belongs to an accelerated frame, or if he is inside a homogeneous gravitational field. It is enough to free a hydrogen atom  $H$  and an antihydrogen atom  $\overline{H}$  and observe their motion, because relative to an accelerated frame both atoms would have the same acceleration, while inside a gravitational field they would move with opposite accelerations. The use of a  $H, \overline{H}$  pair, instead of a charged particle-antiparticle pair (*e.g.*, a  $p, \overline{p}$  pair), can eliminate the many troubles linked to the weakness of gravitational coupling compared to electromagnetic coupling: see, for instance, the analysis made by Holzscheiter and Charlton (Rep. Progr. Phys. **62** (1999) 1), and by Gabrielse *et al.* (Phys. Lett. B **455** (1999) 311); the latter authors have also shown that the possibility of producing “cold”  $\overline{H}$  atoms, is open.
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